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Measuring Impact-induced Deflection with an Observer Spacecraft

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Overview

Radio Science at small bodies

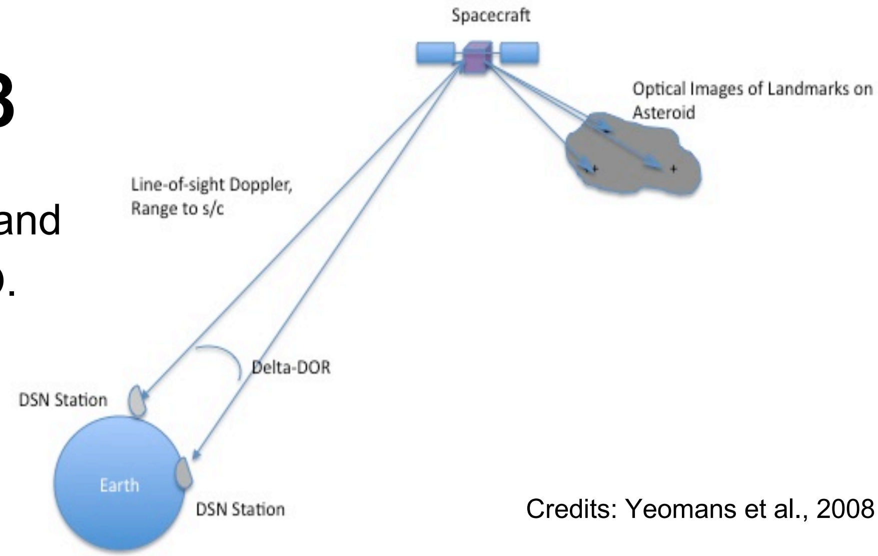
- Results from the B612 study on asteroid impact and tractoring deflection techniques
  - D.K. Yeomans, S. Bhaskaran, S.B. Broschart, S.R. Chesley, P.W. Chodas, M.A. Jones, and T.H. Sweetser, “Near-Earth Object (NEO) Analysis of Transponder Tracking and Gravity Tractor Performance”, final report to B612 Foundation, JPL Task Plan No. 82-120022, 2008

Binary Asteroid Case: AIDA / AIM study

- **Mission objectives and study goals**
- **AIM trajectory**
  - 2km and 5km terminator orbits
  - Flyby approaches (300 m from Didymoon, 1500 m from Didymain)
  - Radio science result tables
  - GM uncertainty as function of orbit altitude
- **Dart impact observation**
  - 100 km and 50 km standoff orbits for DV impact observation

Concluding remarks

B612 Study Report, 2008



Credits: Yeomans et al., 2008

Report addressed asteroid impact deflection and gravity tractor of a potentially hazardous NEO.
→Let's look at the spacecraft
radio tracking conclusions…

Sub-task 3

Looked at quantifying the ability to precisely determine the orbit of the asteroid by tracking a spacecraft in orbit or hovering near the asteroid using standard radiometric and optical navigation techniques. Done for:

1) Pre-impact, precise orbit determination with orbiter
2) Post-impact, determination of DV imparted by impactor using orbiter
3) Post-tractoring, determination of acceleration imparted by orbiter

Assumptions and simulated data:

Asteroid: 140 m in diameter, spherical

Doppler and range, 3 tracking passes per week

DDOR, 2 baseline pairs per week

Asteroid optical tracking, images taken 1 per week, and 4 per day from 2 weeks pre-impact to 4 weeks post-impact

Asteroid Ephemeris Error Improvement

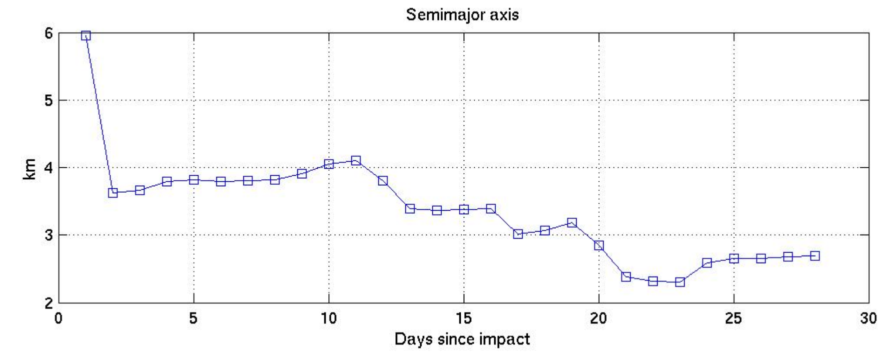
Conclusions from spacecraft radiotracking…

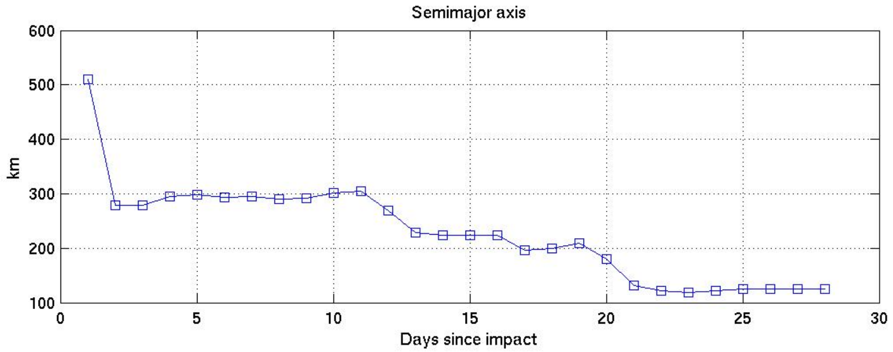
The asteroid's pre-impact trajectory was determined to a value of about 400 km in the semi major axis of the b-plane uncertainty ellipse at the Earth encounter in 2049 (after 8 days of tracking).

Impact at 4.7 m/s +/- 1 cm/s

Following deflection, the asteroid's orbit was determined to its pre-impact levels after only one day of tracking.

→ After only one day of tracking, the semi major axes have been reduced from 2,000 and 200,000 km to roughly 6 and 510 km.





Asteroid uncertainties mapped to the Earth b-plane in September 2046 (top) and September 2049 (bottom) following deflection, as a function of the number of tracking days (post-deflection impact).

Credits: Yeomans et al., 2008

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Radio Science Analysis for the AIDA mission

Terminator Orbits

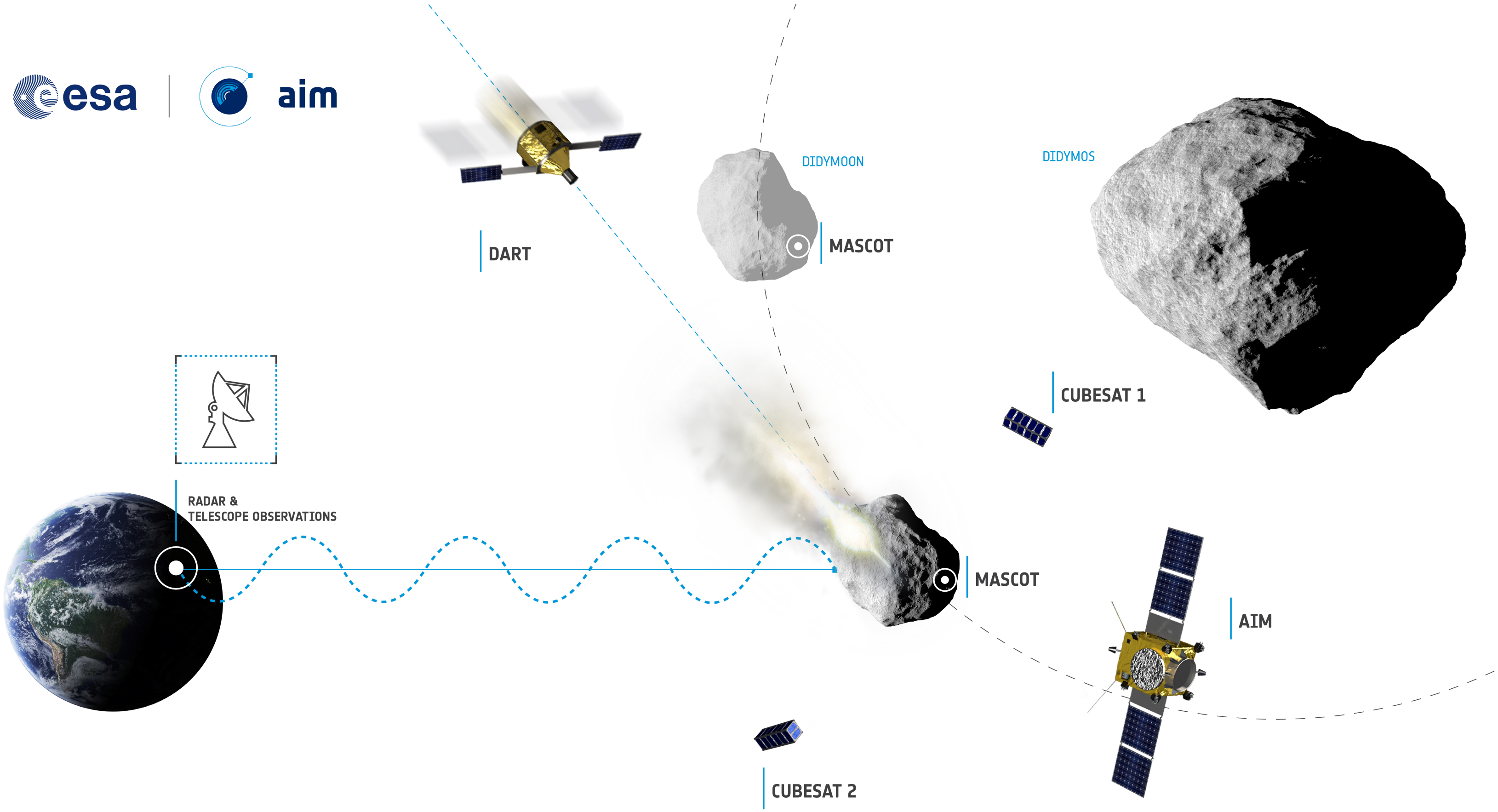
Binary Component Flybys

AIDA Mission Objectives

ESA-led AIM to launch in October 2020.

NASA-led DART to arrive at Didymos in late 2022 and impact the moon at ~6 km/s.

AIM would perform detailed before-and-after impact comparisons.



Credits: ESA

Study Goals

Determine measurability of Diydmos parameters and impact DV from DART

Uncertainty Assumptions

- Didymos system parameters and apriori uncertainties from AIDA reference document.
- Didymos ephemeris and apriori covariance from JPL SSD Alain Chamberlain.
- Didymoon/Didymain orbits integrated using initial conditions from Didymos system ephemerides simulated by JPL SSD Eugene Fahnestock.
- Harmonics apriori uncertainty assumption from Jay McMahon (LPSC 2016)
- Accounting for uncertainties on planetary ephemeris, DSN locations, media

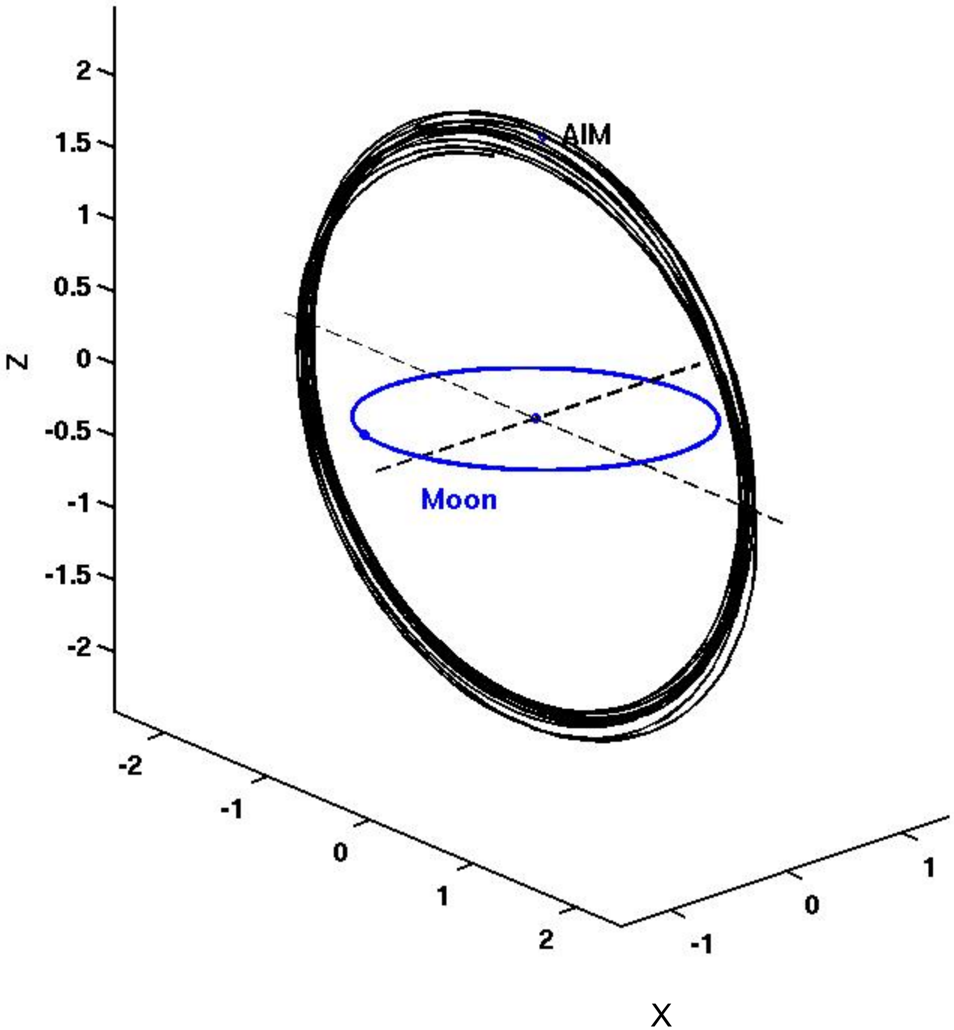
Spacecraft desaturations

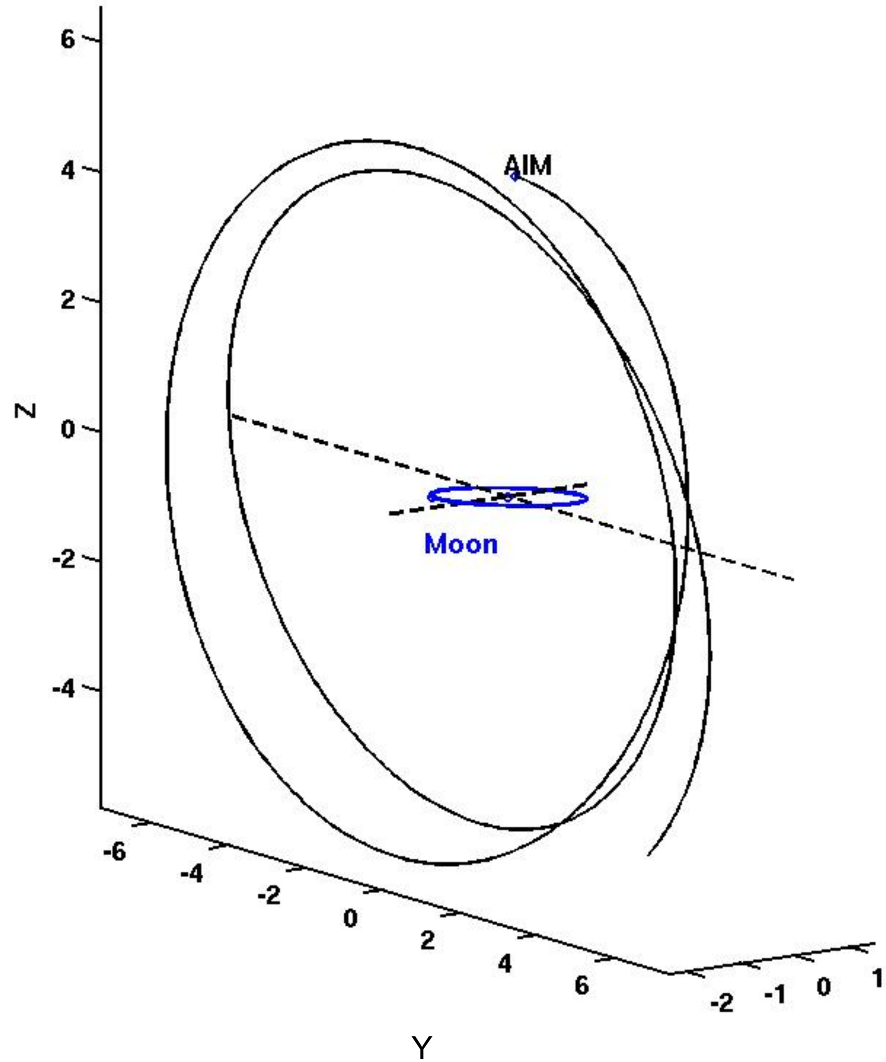
- Modeling spacecraft using desaturations (1x / 2 days) (assume use of reaction wheels for turns, balanced thrusters), and compared with a “clean” spacecraft.

Simulated Data

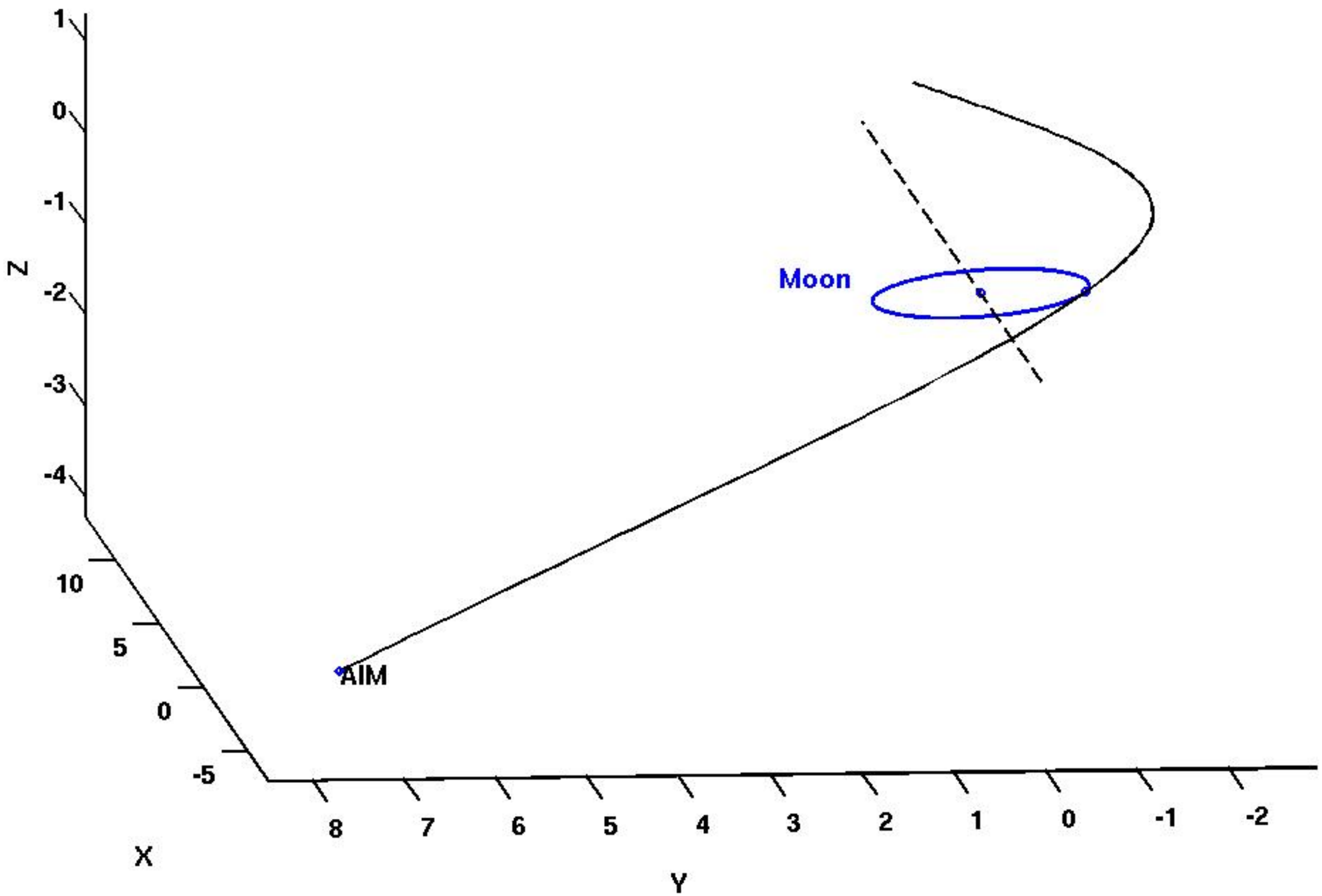
- Simulated radiometric measurements: 7 per week, 8 hr tracks
- Simulated optical measurements (13 deg field of view, 1 pic/12 hrs, alternating between main and moon every 6 hrs, equally generated landmarks)
- Pointing uncertainty not included

2km & 5km Terminator Orbits

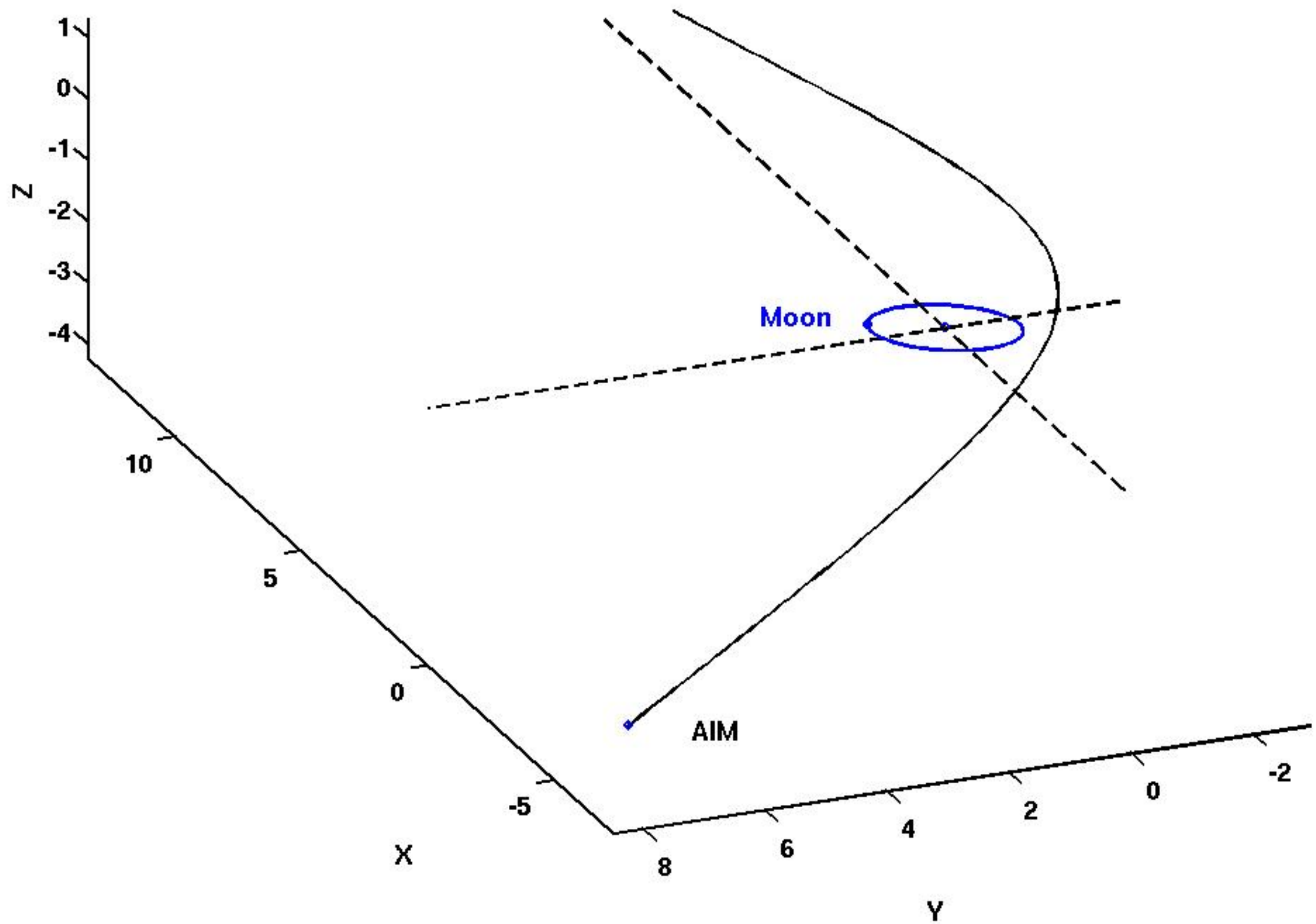




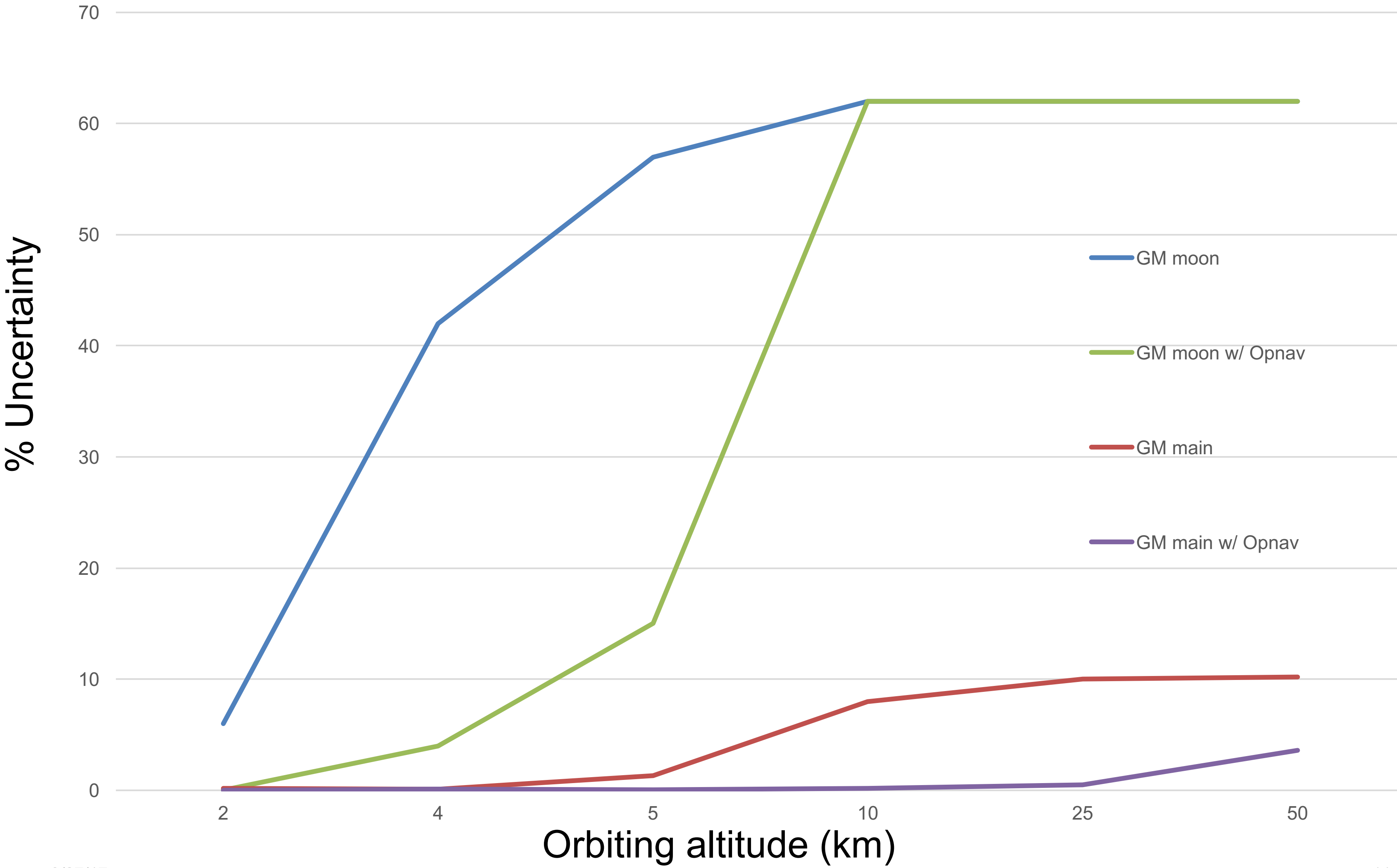
Didymoon Flyby at 300 m altitude



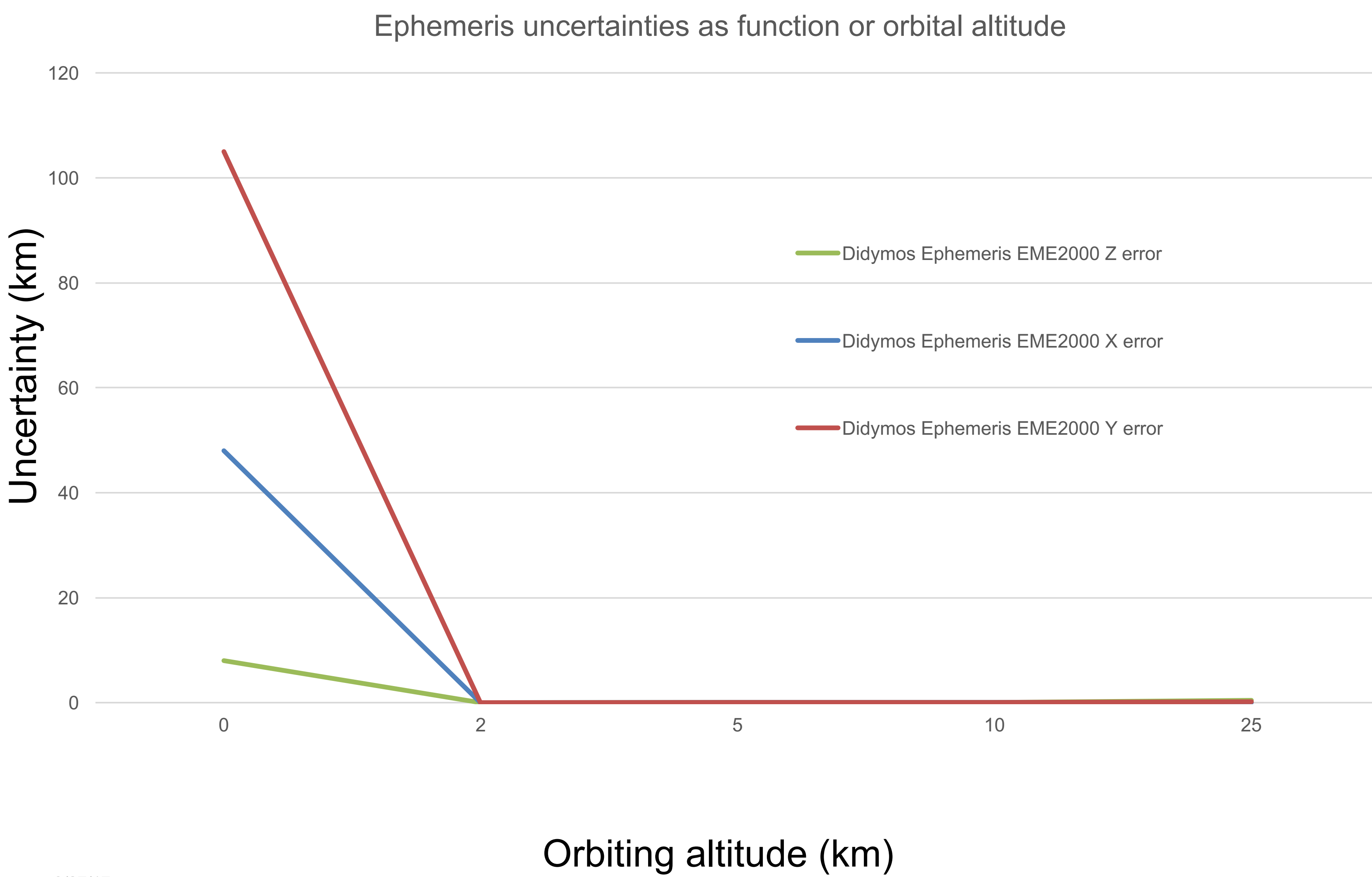
Didymain Flyby at 1500 m altitude



Asteroid GM Uncertainties vs Orbiting Altitudes, with/without Optical navigation



Dydimos Ephemeris Uncertainties vs Orbiting Altitudes, with Optical navigation



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DART - Impact Observation from 50 km and 100 km orbit platforms

Spacecraft Observation Platform

Uncertainty Assumptions – already refined from pre-impact operations

- Apriori covariance on states, GMs, pole data using 2km terminator orbit case
- Accounting for uncertainties from planetary ephemeris, DSN locations, media

Spacecraft orbit maintenance

- From 50km and 100km orbiting platform, over 4, 12, and 31 days
- Impulse maneuver every 4 days to stay within “box” for > 4 days cases
- Uncertainty on DART-induced DV and orbit maintenance impulses is 1 mm/s

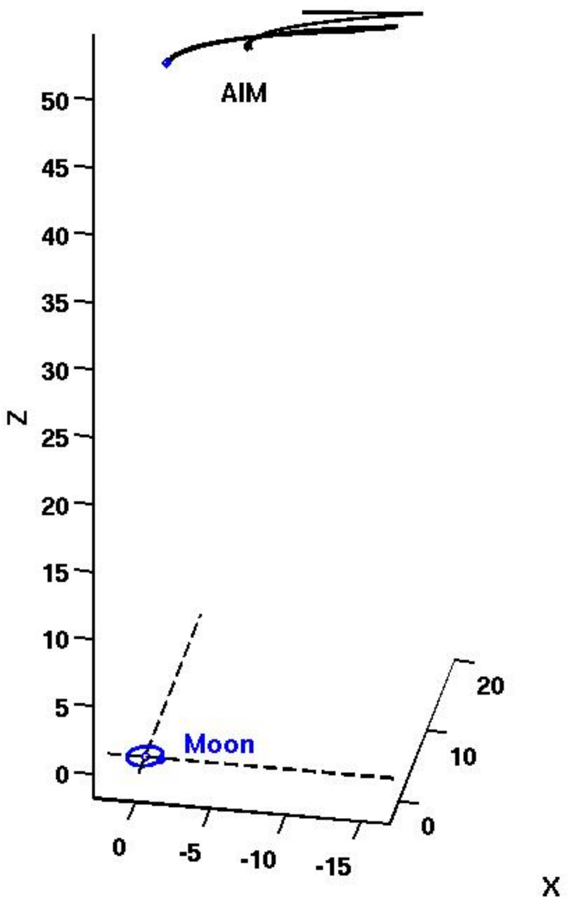
Simulated Data

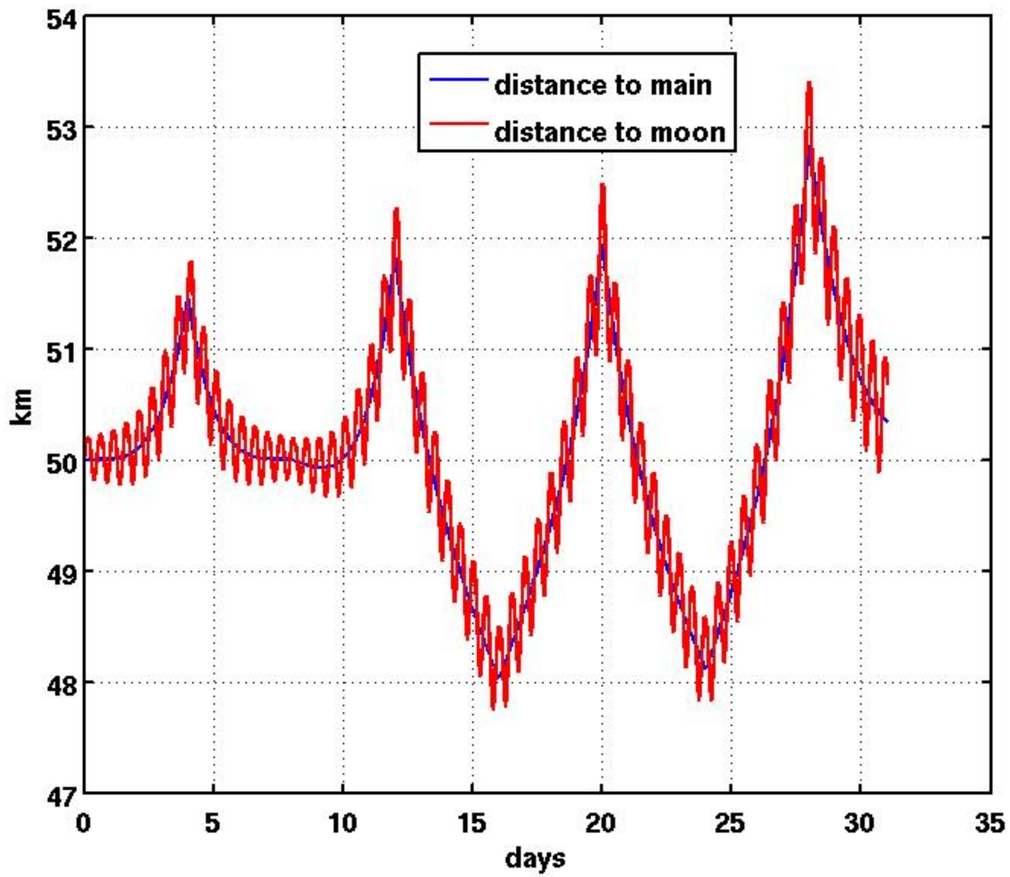
- Simulated radiometric measurements: 7 per week, 8 hr tracks
- Simulated optical measurements: Didymain landmarks and component centroids
- Pointing uncertainty is not included

Parameters of Interest

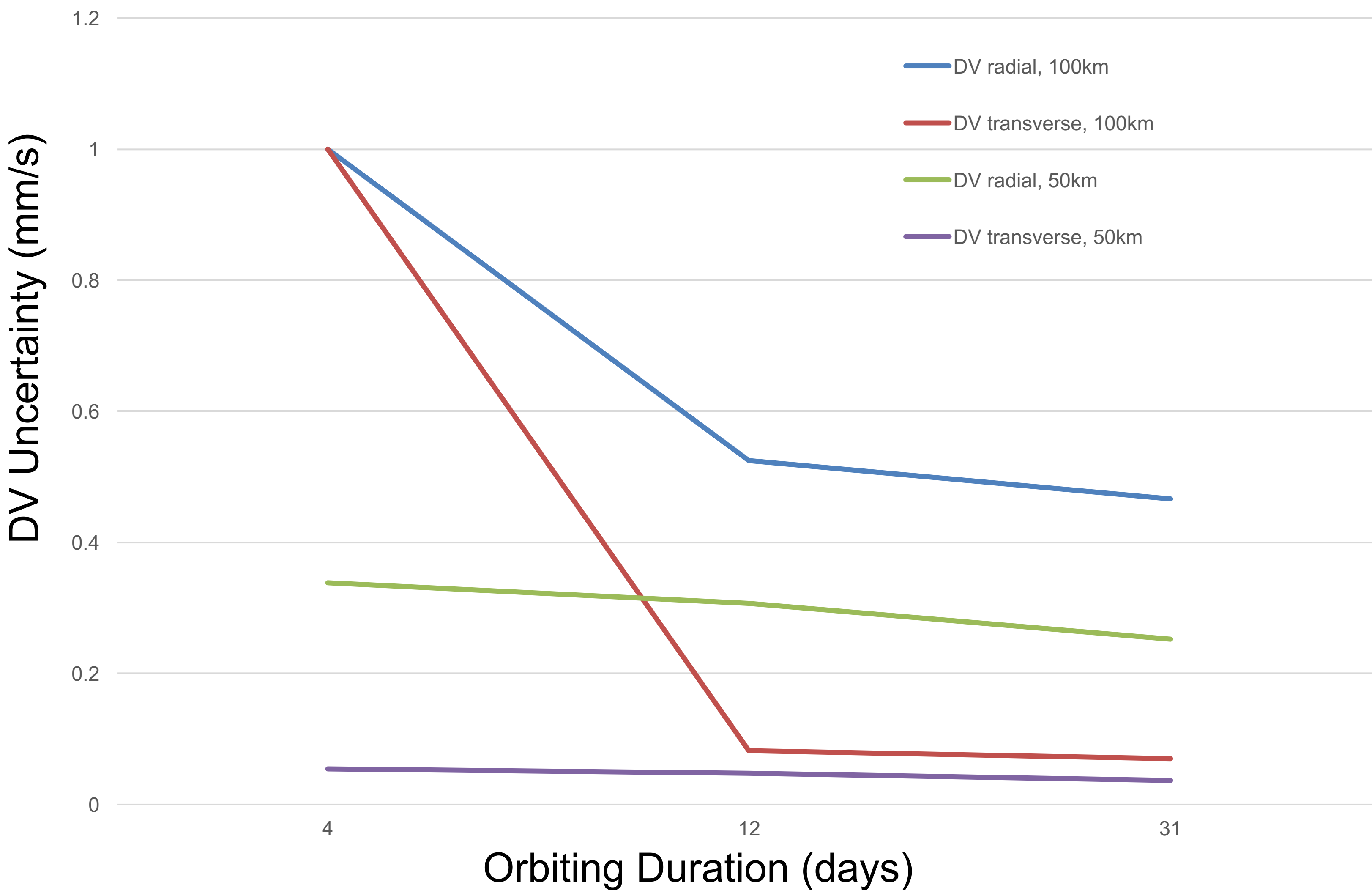
- DV uncertainty in RTN frame: radial and transverse visible from pole observation platform
- Beta uncertainty: take DV uncertainty projected along surface normal at impact location, normalize by impact DV magnitude, obtained for “low”, “moderate”, “high” excitation (see Eugene Fahnestock study cases).

50 km Standoff Orbit

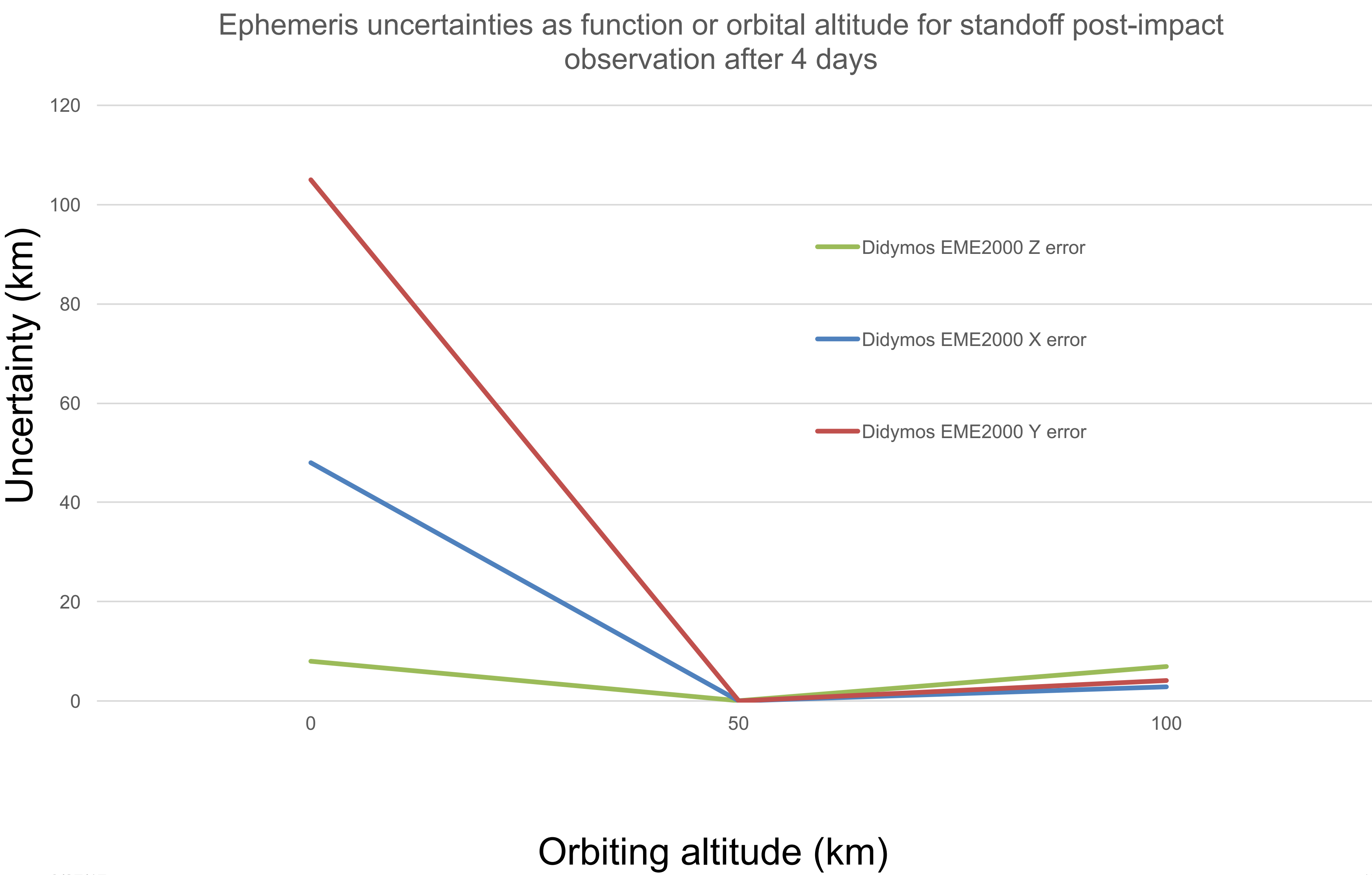




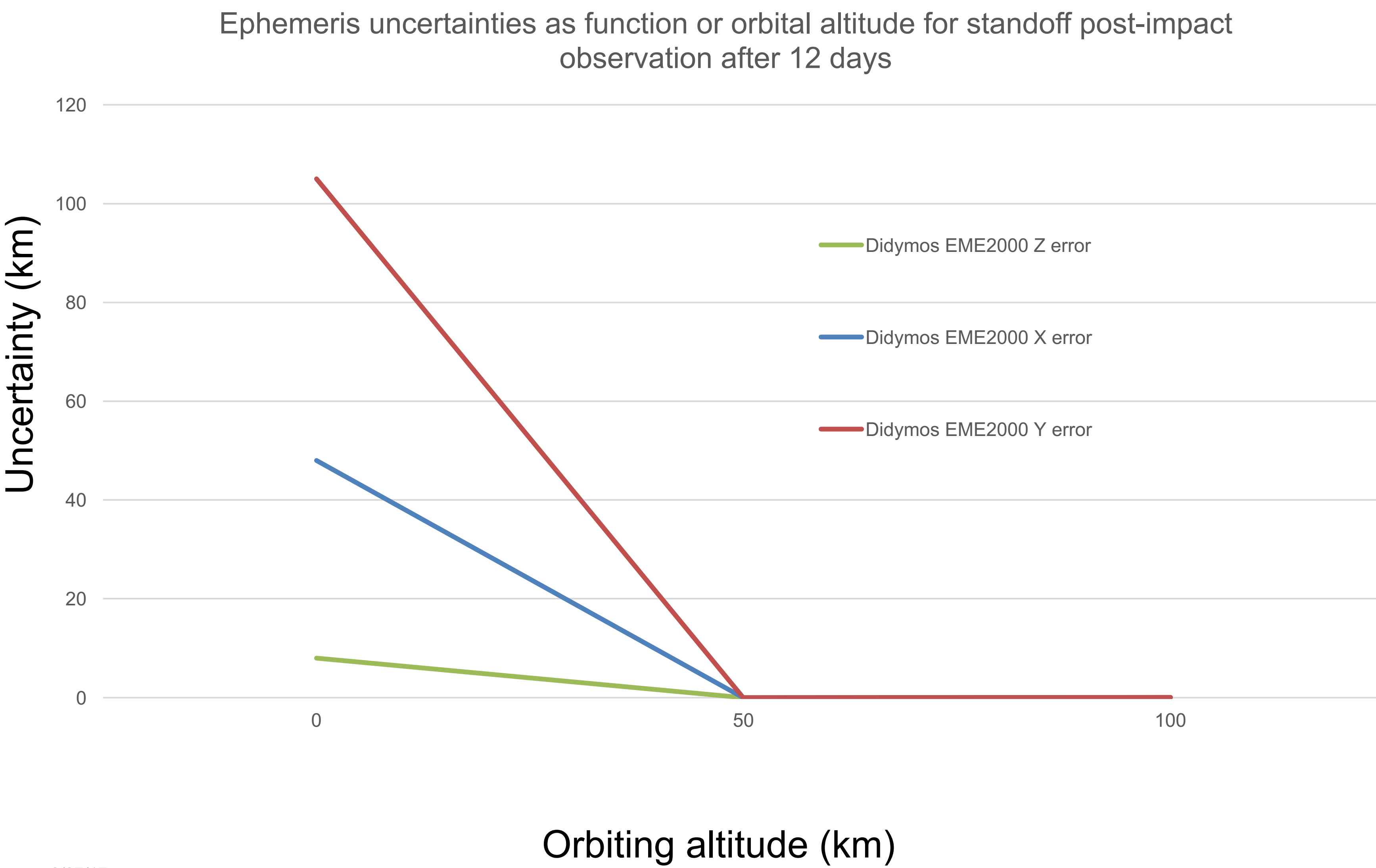
DV Uncertainties vs Time for 100km and 50km Orbiting Platforms, with Optical Navigation



After 4 days… Dydimos Ephemeris Uncertainties vs Orbiting Altitudes, with Optical navigation



After 12 days… Dydimos Ephemeris Uncertainties vs Orbiting Altitudes, with Optical navigation



Conclusions

From the 2011 B612 report:

→ The asteroid orbit can be determined to its pre-impact levels after only one day of tracking.

→ Further improved as more radio tracking and optical measurements are obtained.

From the AIDA case study:

→ The GM of the main and moon asteroid can be determined to less than 1% for the main with orbit altitudes below 10 km, and to less than 5% for the moon with orbit altitudes below 4 km.

→ Didymos ephemeris errors reduce to sub-km with terminator orbits at altitudes below 4 km, and to km-level with hyperbolic flybys.

→ After the DART impact, ΔV uncertainty < 0.05 mm/s can be obtained (in transverse direction from a pole observation) with orbiting platform at 50 km over a week. ΔV uncertainty < 0.1 mm/s with orbiting platform at 100 km over 30 days.

→ Didymos ephemeris errors reduce to km-level and sub-km after 4 days and 12 days from an orbiting platform at 50km, respectively.